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MILITARY GEOLOGY

Chapter 6. UNDERGROUND MINE WARFARE

[Figures referred to herein are not reproduced but are available in the original document at the US Geological Survey.]

General and Historical

[The first section, entitled "General Information Concerning Underground Warfare," defines the subject of underground mine warfare, distinguishes between attack and defense and stresses the necessity of accurate information of the area in which underground mine warfare is conducted.

[The next section is entitled "Underground Mine Warfare in Past and Contemporary Wars." After mentioning a few examples of mine warfare in the 16th and 18th Centuries, it treats the defense of Sevastopol as the classic example of underground mine warfare.]

At Sevastopol, the mine warfare before Bastion No 4 was particularly instructive. Geological conditions there influenced greatly the course of the fighting, limiting both offensive and defensive plans.

From the longitudinal cross-section diagram of the Russian galleries shown in Figure 27 it is obvious that the area is composed of hard, solid limestones, in which there were layers of clay at depths of 5 and 12.5 meters. The first layer of solid clays (thickness 1.2 - 1.5 meters) permitted the installation of galleries without revetment (dimensions 0.9 by 0.75 meters). The walls were reinforced only in places and for short distances. All of the French and the greater part of the Russian mine galleries were laid at this level.

The galleries were often inundated with ground water, since the layer (clay) of water-permeable clays in the roof was cracked in many places or was so thin that it permitted the seepage of water. There was

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frequent crumbling in the walls and the ceiling, which seriously delayed work and in certain cases stopped it altogether. The clays of the second layer below were soft and plastic and required continuous bracing. The Russians constructed a number of countermines in this lower layer of clays. This gave assurance and raised the spirits of the garrison, since until then it feared being blown up from below.

During the entire seven-months period of mine warfare, the Russians, not having any previously prepared countermines, constructed about 7,000 linear meters of galleries and sleeves (rukav), expending 12,000 kilograms of powder on 94 blasts, while the French constructed only 1,260 linear meters and expended 54,000 kilograms of powder on 136 blasts.

The peculiar nature of the Russian mine operations lay in their offensive tactics; the Russian countermines not only hindered the progress of the attackers' underground operations but constantly pushed them back.

The experience of Sevastopol in connection with underground mine warfare was not taken into account by the command of the Czarist army, as was disclosed in World War I and even earlier at Port Arthur, where no countermine system was prepared beforehand, and where it was not possible to set one up when war brokeout, because of the lack of previously prepared cadres and the poor technical equipment of the army. The Czarist command tried to justify its inactivity on the ground that the Japanese would not succeed in constructing mine galleries in rocky ground. And only when a Japanese gallery was within 30 meters of the foot of Fort No 11, did the defenders begin to construct a mine gallery.

The war with the Japanese showed that underground mine operations can be conducted not only in an area of fortifications but also in field positions. It was waged at the time of the famous "Shakhe deadlock" on the Shakhe River, from November 1904 through February 1905, where Russian positions in some places were only 140 to 280 meters from the Japanese.

[During the early phases of World War I both Russian and Germans made little use of underground mine warfare. But by the middle of 1915 a marked change had taken place in this respect. The text describes the intensive preparations for underground warfare and selects for extensive treatment the underground mine operations in the Messine-Vitshaete (transliteration of the Russian spelling) sector in France.]

In the Finnish campaign and on various fronts of World War II, the Red Army also found it necessary to use underground mine warfare.

Often it was necessary to undertake underground mine operations in order to cover up the approach of troops to the enemy's main line of resistance and to secure a jump-off position for attack and breakthrough of the fortified zone. One way of approaching the enemy under cover is by means of "sapy."

"Sapy" -- narrow, deep ditches -- were used in earlier wars in the siege of fortresses and strong points, approach to which was open to tactical observation of the defenders and was covered by fire. "Sapy" operations were widely used in the Sevastopol Campaign in 1855-1856, in the Japanese siege of Port Arthur in 1904-1905, and in many sectors of the fronts of the World War of 1914-1918. Often "sapy" were the only means permitting an approach to the enemy's fortifications for the purpose of destroying them or taking possession of them, insofar as there were no other means of breakthrough (heavy artillery, tanks, aviation).

It was often necessary to have recourse to "sapy" work during the Finnish Campaign of 1939-1940 in the Karelian Isthmus. "Sapy" found rather wide use in various sectors of the front in the Great Fatherland War.

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"Sapy" work can be carried on at a definite distance from the enemy; one cannot successfully advance closer to the enemy than 60-70 meters because of mortar and grenade fire. Only underground mine galleries permit a close approach to the enemy's position. Sometimes that approach is effected by means of exploding a whole series of mine charges (gorny) resulting in the formation of craters which are occupied by the attacking infantry. In order to continue the mine attack, new mine galleries are constructed from the bottom of the craters in the direction of the enemy's positions.

These methods of work, even when conducted under favorable geological conditions and in the absence of previously prepared enemy countermines, cannot be considered as the most desirable, since they consume a great deal of labor and time. However, in many cases, in the preparation of a bridgehead and in the approach to an especially important enemy objective, it is necessary to have recourse to mine work.

Thus, on the Bryansk front during World War II, our forces were unable to take a tactically very important height for a long time, in spite of intense artillery preparation and aerial bombing. The Germans beat off many attacks by our troops, inflicting serious losses on us, and only after the construction of three mine galleries and the explosion of charges was the height taken without excessive losses.

In another case, in attacking a carefully camouflaged enemy pillbox well adapted to the terrain and situated near our forward edge, it was impossible to use artillery or aviation because of the danger of striking our own forces. Approaches toward the pillbox were covered by intense enemy fire. The only suitable means of approaching and blowing the pillbox, therefore, proved to be underground mining operations. Mine galleries combined with "sapy" and trenches permitted approaching the enemy with impunity and destroying the pillbox by exploding a powerful mine. As a result of the explosion a crater 22 meters in diameter and 8 meters deep was formed (See diagram and cross section of the approach to the pillbox in Figures 30 and 31).

In military operations conducted in large populated centers, mine galleries are used chiefly for the purpose of breaking down the fire system on the edges of the towns, since the area before the enemy's forward edge is usually so well covered by fire that infantry often cannot follow the tanks. The most striking example of successful application of underground mine attacks in large cities is that of the fight of our troops at Stalingrad. Mine galleries, lying not very deep, permitted the undermining and blowing up within 3 or 4 days of various buildings which had been transformed into centers of resistance.

During World War II especially wide use was made of the so-called "beneath-the-surface" (podpoverkhnostnyy), i.e., shallow-lying, mine galleries.

On one of the fronts of World War II, the following destruction of one of the enemy's centers of resistance was effected by means of underground mines. The Germans were very heavily fortified in the area of a city situated on the banks of a rather large river. The right-bank part of the city was occupied by our troops, but on the left bank we occupied only a small part of the city's territory, and the German position wedged deep into our defense, occupying the highest section which dominated the surrounding area.

Numerous ground attacks by our troops with air support failed, since the approach to this strongly fortified zone across open spaces was under good observation of the enemy and covered by his fire; all buildings were destroyed and wooden structures burnt. It was decided to construct a system of underground mine galleries to blow the German fortified centers of resistance.

As a result of engineering reconnaissance consisting in the examination

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of the walls of many hollows and craters of different sizes, with which nearly the whole place was pitted, the command was informed "that crumbly sandy loam lay to a thickness of no less than 4 to 6 meters below the surface, that these layers contained a considerable number of boulders of various sizes and thin layers of gravel that the water-table level was 3.5-5 meters below the surface (dnevnaya poverkhnost -- daylight surface).

The command had no information as to the kind of strata to be found below the sands or the depth at which these strata replaced one another; the engineering reconnaissance had not taken into consideration the available geological data. The geological structure could have been easily ascertained from special maps available and from the cross-section of a prospecting pit sunk earlier in this region to a depth of 27 meters, and also by studying the exposed strata in the sloping banks of the river.

From the cross-section of the prospecting pit and from the exposed strata it was possible to detect that the sands were quickly replaced by dry, morainic, clayey soil containing a small number of boulders. The thickness of these clayey soils varied on the average from 5 to 6 meters and only in places diminished to 3.0 - 3.5 meters. Still lower, i.e., under the clayey soils, lay the water-carrying, fine-grained sands of considerable thickness. (Their bottom was not established in the nearby exposed strata).

/With limited information at its disposal/ the command gave orders to build underground galleries in the sands above the level of the water-table. Since the depth of the water table was not great, and accurate data on the relief was not available, it did not seem possible to set any figure for the protective thickness /of the ceiling ?/and follow it consistently. It was decided to lay the galleries by following the water table, thereby precluding the danger of piercing through to the day light surface. /Overhead covers (blindazh) were created, which were used for storing instruments, and from which the digging started at a depth of 2.5 to 3 meters./

In spite of continuous reinforcing, cave-ins began to occur in the first 10 meters, the number and magnitude of which increased in proportion as the stope was removed from the entrance, since in approaching shell craters the sands would crumble at the slightest shaking. Aside from the great expenditure of time the extra work of fighting cave-ins (up to 69 - 70 percent of all working time was spent in reinforcing), the cutting of the galleries was greatly impeded by frequent large boulders which had to be by-passed, and in consequence of which the galleries sometimes diverged from the planned direction by several meters.

/Among other difficulties encountered was that of disguising the noise of excavation work carried on at close range to enemy defenses./

In order to disguise the work of underground cutting and reinforcing, the operations were often carried on at night and accompanied by heavy rifle, machine-gun and mortar fire. The delays which resulted from this made it impossible to complete the work in time. When the Germans took the offensive it became necessary to abandon the excavation work, which was resumed only in the winter.

It turned out that under the soil conditions described above, digging of "beneath-the-surface" galleries in winter was incomparably more effective, since the frozen top layer of soil served as protection against cave-ins and made it unnecessary to reinforce the walls everywhere. /Excavation work greatly increased, and the mine galleries were completed./

<u>Underground Mine Installations and Charges</u>

Underground structures built for waging mine warfare, which is aimed at the reduction of enemy fortifications, the destruction of his personnel,

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and repulsing mine attacks by means of underground explosions, bear the name "mine structures."

Every mine structure consists of:

1. Entrances for communication with the daylight surface.

2. Galleries for advancement to the targets of mine attacks.

3. Sleeves (rukav) -- galleries of smaller cross-section, cut either as the continuation of the main galleries or in a lateral direction to protect the flanks, and to secure ventilation, water supply, etc.

4. Chambers -- excavations in a dead-end section of a gallery for placing explosive charges.

5. Perforated tubes (burovyye truby): combat tubes to hold explosive charges; listening tubes to listen to the mine operations of the enemy; and many others, for ventilation, water supply, drainage, etc.

6. Combat wells -- at the bottom of which explosives are placed.

Mine entrances are vertical (mine-shaft type), inclined (mine-slope type) and horizontal (tunnel type). The most convenient entrances are those of the tunnel type, which are used only on steep slopes (steeper than 30 degrees). They are sloped at 0.03-0.05 to allow for water drainage. Sloped type entrances are usually constructed with a slope of 60 degrees in rocky or semi-rocky strata, of 45 degrees in clayey strata and up to 30 degrees in sandy or gravelly strata. Mine-shaft-type entrances are constructed in horizontal areas and most often in water-bearing and unstable strata. In digging through water-bearing layers (sloy) and quicksands, timber pilings in the shape of grooved boxes are used, out of which the stratum is dug and the water is pumped. Concrete collars (kol'tso) and other methods of digging are used.

Entrances are sometimes round but more often rectangular, with cross sections of 0.9 x 0.9 meter; 1 x 1 meter; 1.2 x 1.2 meters; 1.5 x 1.5 meters and larger.

Mine entrances are situated in sheltered, well-camouflaged places on reverse slopes, for example, and against the direction of prevailing winds. They are spaced at intervals no closer than 20 - 25 meters, to prevent destruction or caving-in from bursts of large-caliber shells and aerial bombs. It is not advisable to locate entrances in hollows or depressions, where poison gas may stand too long, or in sectors where surface water in the rainy season or the melting of snow or subsoil waters may flood them.

In lowlands where either the sloped-type or shaft-type entrances are used, a protective layer of water-impermeable strata (poroda) about 2 meters thick should be left untouched. In order to prevent access of surface waters into a sloped entrance, a water-collecting well is dug in front or inside the entrance. If geological conditions permit, the water-collecting wells should go down to the water-absorbing layers (sloy). However, construction of such water-absorbing wells is in many cases impossible, since the waters from them might gain access to the mine gallery, as is shown in Figure 32.

Mine galleries are either horizontal or sloping (descending or rising). Their dimensions are : 1 meter (high) x 0.75 meters (wide); 1.2 x 0.9; 1.3 x 0.9; 1.5 x 1.2; 1.2 x 1.35; and up to 2 x 1.8 meters.

A mine chamber with a previously prepared explosive charge is called a mine. Mines of the defender, in contrast to the mines of the attacker, are called countermines. Depending upon the nature of their effective action, mines are divided into outer (naruzhnyy) or underground action. The former

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produce craters in the earth's surface with a circular embankment or create a bulge and are called bulging mines (vypirayushchiye miny). The latter, called camouflets, do not break the surface of the ground.

Upon explosion of an outer-action mine a crater is formed with depth "p." The distance from the center of the charge to the surface level on which the activity of the explosion is aimed is called the "line of least resistance" (LLR) and is designated by "h." The radius of the crater is designated by "r" and is measured on the earth's surface. The relation of the crater's radius, "r," to the line of least resistance, "h," is $\frac{r}{h}$ and is designated by "n." With reference to "n," mines are classified into: normal ($n = 1$; $r = h$), amplified ($n > 1$, $r > h$), and reduced ($n < 1$, $r < h$).

Bulging mines and the largest types of camouflets are used mostly as reduced mines.

Normal and amplified mines are used to form craters in mine warfare, to destroy enemy fortifications, to demolish enemy countermine systems, to build trenches and communication trenches, to blow passages through wire entanglements, etc. Bulging mines and the largest camouflets are used by the defense to blow the mine system of the attacker, to destroy reinforced-concrete firing points, etc.

As regards their relative positions, mines are either single (their craters on areas of demolition do not intersect each other), adjacent (their craters or demolition areas touch or intersect each other), or in tiers (with charges placed at various depths).

Computation of the size of the charge of mines is done by a specialist in blasting work -- a mine expert (miner). But the military geologist can render him great aid by indicating the peculiarities of the geological structure and the hydrogeological conditions of the area, since the size of the charge and the effect of the explosion are determined in a great measure by the character of the strata and their stratification.

Charges of single mines are computed according to the formula:

$$C = Kh^3 (0.4 + 0.6n^3)$$

where C is the charge in kilograms;
- K is the coefficient, varying with the strata and the explosive material.
- h is the line of least resistance in meters.
- n is the index of the mine's action ($n = \frac{r}{h}$)

The value of K is taken from Table 10 (see below). However, that coefficient is best selected by the miner in consultation with the military geologist, since it depends upon the contents and nature of the strata.

The weight of a bulging mine charge is equal to 0.4 (two fifths of the charge of normal mine); the weight of the biggest camouflet mine charge is 0.2 (one fifth of the normal charge).

When confronted by heterogeneous strata consultation with the military geologist is especially urgent. When the strata are more or less parallel to the exploded (horizontal) surface (Figure 34) the charge of the mine is determined by the sum of charges required for each layer separately, in accordance with the following formula:

$$C = [K_2 (h_2^3 - h_1^3) + K_1 (h_1^3 - h^3) + Kh^3] (0.4 + 0.6 n^3)$$

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where h, h_1, h_2 are the distances from the center of the charge to the outer surface of the corresponding layers;

and K, K_1, K_2 are the corresponding values of the coefficients of the strata and the explosives.

When a gallery is blasted, the greatest distance from the center of the mine to the gallery is called the radius of destruction. A distinction is made between the horizontal radius of destruction (R_g), which is a horizontal (large) semiaxis of the ellipsoid of destruction, and the vertical radius of destruction (R_v), which is the vertical (small) semiaxis of the ellipsoid.

The shortest distance from the center of the mine at which the gallery is not destroyed is called the radius of safety (of concussion [sotryaseniye]). The horizontal radius of safety (S_g) is the horizontal (large) semiaxis of the ellipsoid of safety; the vertical radius of safety (S_v) is the vertical (small) semiaxis of this ellipsoid.

In computing the radii of destruction and safety, the following formulae are used:

Vertical radius of destruction:

$R_v = mh\sqrt[3]{0.4 + 0.6\,n^3}$ (amplified mine, $n = 1$-3);

$R_v = mh$ (normal mine, $n = 1$);
$R_v = 0.7\ mh$ (bulging mine, $n = 0.6$-0.7);
$R_v = 0.57\ mh$ (largest camouflet, $n = 0.5$-0.6).

In these formulas "m" is the coefficient which varies with the strata (for sands, - 1.5; for clays, - 1.36 to 1.43; for rocky strata, - 1.0 to 1.2). The other symbols were explained above.

If the vertical radius of destruction R_v is taken as equal to 1, then the horizontal radius of destruction $R_g = 1.4\ R_v$, the vertical radius of safety $S_v = 1.4\ R_v$ and the horizontal radius of safety $S_g = 1.75\ R_v$.

A mine attack in most cases begins with the construction, in the rear of fire positions, of a mine trench, in which are found entrances to the galleries for the offensive. Entrances to mine galleries can be constructed immediately from the surface only under favorable relief and camouflage conditions, generally on steep reverse slopes.

The number of offensive galleries is determined by the tactical problem, the available time, technical means and geological conditions of the area.

Table 10. Values of Coefficient K for Various Strata and Soils

This table gives data for ammonite and TNT. Explosives of reduced strength should be compared to ammonite, and of normal strength to TNT. When fissures are present, the values of K may be divided by 1.5 or 2.

Strata and Materials	K Ammonite	K TNT
Newly filled-in, crumbly, humus soil	0.5	0.43
Sandy, humus soil	0.95	0.82
Solid, clayey, humus soil	1.10	0.95
Humus soil with gravel	.98	.85
Solid, pure sand	1.20	1.03
Wet sand	1.27	1.10
Sandy loam	1.29	1.11
Humus soil mixed with stone	1.36	1.17

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Table 10 (Contd)

Strata and Materials	Ammonite	TNT
Solid clay and clayey soil	1.37	1.18
Clay or sandy loam -- stony	1.50	1.29
Clay with boulders	1.64	1.41
Sand with gravel and boulders	1.65	1.42
Very solid clay	1.90	1.64
Limestone without fissures	2.15	1.87
Granite and gneiss	2.58	2.26
Masonry of natural stone	1.06-2.82	0.94-2.45
Concrete	3.59	3.12

Figure 35 is a diagram of the disposition of three mine galleries in an attack on a fortified area of the enemy. The galleries must not be situated so close together that the enemy could destroy two adjacent galleries with one blast. The distance between the galleries should be no less than 2.5 of the line of least resistance. For protection against enemy attack, branch galleries, called "sleeves," are constructed from the outer galleries. Sleeves are put out from other galleries only when the latter are widely separated and are few in number.

Two-story galleries are sometimes constructed. The purpose of the upper gallery is to divert the enemy's attention from the basic operation in the lower story, to provoke the explosion of his charges prematurely, and to destroy his countermine system. The minimum vertical separation must not be less than the radius of the sphere of destruction from the explosion of the charge of the upper story.

In mine defense the same types of underground mining are used. In highly fortified areas, countermine systems are constructed beforehand, most often of concrete, reinforced-concrete, or metallic jacketing. When a mine attack is anticipated the countermine system is developed and extended.

Basic Tactical and Technical Requirements of Geology and Hydrogeology

In the erection of mine structures a great many demands are made upon the geologist. Chief among these are the following:

1. Mine excavations should be undertaken in strata which are easiest to work and yet sufficiently stable and impervious to gas.

2. Care should be taken that mine constructions are not flooded by subsoil waters.

3. All mine structures, with the exception of the so-called "beneath-the-surface" [type], must have in their roofs a thickness of the protective layer (tolshcha) which affords adequate protection against anticipated weapons of attack.

4. Mine structures must not be erected in filled-in slopes or in slopes endangered by landslide, cave-in or other physicogeological phenomena.

5. [Stresses the need of proper concealment and camouflage during excavation.]

6. Mine galleries must be dug in geological strata which would create the greatest difficulty for the mine work of the enemy (the strata below the bottom of the galleries should be of a kind that is difficult to work or water-bearing -- containing pressure waters, etc.)

7. Mine work must be protected by appropriate underground reconnaissance

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aiming at the detection of the enemy's underground work, as well as obtaining necessary geological information for the construction of one's own mine galleries and enemy countermines.

The success of underground mine work depends in varying degrees upon a number of natural factors, chief among which are subsoil waters, the composition of strata and the conditions of their occurrence.

[The section entitled "The Rôle of Surface and Subsoil Waters" reiterates the difficulties resulting from subsoil waters in underground mine construction and lays down rules to overcome these difficulties. Entrances and galleries should not be dug in water-bearing strata. If however, this cannot be fully avoided, care should be taken that a water-impervious layer is left in the ceiling of the gallery. Similarly a protective layer is to be secured when the gallery is above a water-bearing stratum. The thickness of the protective layer is to be determined by the formula $h = \frac{B}{\gamma}$, where B is the amount of pressure in meters and γ is the volumetric weight of the layer between the floor and the water-bearing stratum. If "h" is less than $\frac{B}{\gamma}$ the gallery will be flooded.]

[The following section, entitled "The Properties of strata which contribute to the success of underground mine construction," lists such properties as the ease of processing, resistance to drilling, stability of the walls and the ceiling.]

Significance of the Conditions of Occurrence of Strata [poroda]

The conditions of occurrence of strata play an important part in underground mine warfare. They often determine the tactics of waging underground mine warfare and the selection of levels (gorizont) for mine galleries which insure the quickest passage and permit advantages over the enemy both in mine attacks and in beating off enemy counterattacks.

If the strata are horizontal and coordinated and their thickness is more or less sustained, no difficulties are met in the selection of mine levels or in the working out of plans for mine attack.

These questions are worked out most simply in regions where the horizontally stratified original layers are covered by a thin spread of quaternary deposits. Under such conditions the geologist can establish a geological cross section comparatively easily, and the selection of one or several layers (plast) for the excavation of mine galleries can be made rapidly and unerringly.

Complications arise in mine construction when the borders of the layers (plast) are uneven, especially if the formation of the original strata is deeply grooved by an ancient wash out, levelled off, and unnoticed in the contemporary relief, in the layers (tolshcha) of glacial deposits with frequent changes in the thickness of the layers (plast), in a zone of slipping strata (poroda), etc. In all these cases, a careful and detailed investigation of the geological structure of the area is required.

Even more complicated is the question of selecting mine levels and formulating plans for conducting mine warfare in those areas where the strata are crumpled with folds, broken up with faults, notched with veins, etc. In such conditions, as a result of the shift of strata of varying processability and variable conductivity of water it is necessary often to abandon the waging of underground mine warfare.

A sloping drop of layers (plast) on the side of the attacker with a rise in the direction of the enemy's position is favorable for the excavation of mine galleries, since this facilitates haulage of the excavated material as well as drainage of the installation in case of water seepage. However, if

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there is a sharp drop of layers, especially on the enemy's side, the success and expediency of waging underground mine warfare are doubtful.

When there is a broken occurrence of strata it is difficult to forsee the possible measures of the enemy. The stratification of layers also exerts a great influence on the conditions of sound camouflage, on overhearing the enemy's excavation work, on the size of the explosive charge, etc.

Stability of Strata in the Ceiling and Walls of Underground Installations

The cutting of strata in underground excavations causes a redistribution of stresses in the ceiling, which results in the caving-in of the roof, exfoliation, landslips and buckling of the crumpled strata, and shrinking and distortion of the constructions.

In order to protect the underground structures from deformation and to facilitate further work, reinforcements which absorb the stress are used. This stress of strata is called "mountain stress."

The amount and direction of the mountain stress depends upon the composition of the strata, their stratification, the degree of their decomposition, water saturation, the depths of location of the constructions, etc.

Certain strata, such as stratified marl, after they are uncovered in the excavation, quickly change their firmness. Strata of this type are said to have "subsequent fragility." Fragments of such strata become detached from the ceiling and walls of mine galleries and chambers.

The "subsequent fragility" of strata usually increases with greater fracturability and weathering of the strata, as well as with the increased dimensions of underground works.

Strata as Protective Layers

Underground excavations must be protected from above by layers of strata to withstand destruction by shells and aerial bombs. The thickness of the protective layer is determined on the one hand by the calibre of the shells or aerial bombs and the character or dimensions of the construction, and on the other hand, by the composition of the strata and their vulnerability to shells and aerial bombs. Tables 7 and 8 [not reproduced] give the values of protective layer thicknesses in relation to strata and the caliber of shells or bombs.

In the opinion of certain military engineers, field underground work can go on irrespective of the arch of stress; only the work of the inner bracing has to be taken into account, in which case the thickness of the protective layer diminishes.

As far as protection from bullets and fragments is concerned, it is quite sufficient to leave a layer of stratum 0.5 meters thick over the ceiling. Shallow construction of the "beneath-the-surface" type are being ever more widely used at the present time, since aside from affording some protection from hits, they allow execution of numerous works (underground mining, underground communication trenches, etc.) concealed from the enemy.

This method of mine work takes on especially great significance in winter when the frozen ground has far greater resistance to penetration by bullets and fragments and at the same time supports the ceiling better without requiring bracing.

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Size of Charge and Effect of Explosion on Properties of Strata and Conditions of Stratification

In underground mine operations the objective is to destroy, by means of explosions, only a definite part of territory and, with camouflets, only a definite zone of strata. Therefore, the question always arises as to how much explosive material it takes to attain the required result. If the charge is too small, the explosion does not reach its goal, and conversely, if the charge is too great the resulting explosion is so strong that the sectors and structures which ought to have been saved are also destroyed. The experience of underground mine warfare has taught that such disproportionately great explosions not only destroy the plans of mine warfare but also cause harm to one's own troops and fortifications. A good example of this was the inordinately large mine charges exploded by the Austrians in the Saint-Simon area on September 23, 1916, which inflicted great damage to the Austrian positions.

The size of the charge depends, on the one hand, upon the type of explosive used and the depth at which the charge is placed and, on the other hand, upon the composition, the properties, and the conditions of the occurrence of strata above the place of the explosion.

It is known that massive rocks (skal'naya poroda) when blasted behave differently from schistose strata, and that the effect of an explosion upon thick layers differs from that on thin ones. Explosive waves are best propagated longitudinally through rocky layers, and worst perpendicularly to the direction of stratification, particularly if the dense layers are alternated with weathered clayey deposits and other interstratifications. The effectiveness of an explosive charge will not be the same in layers lying horizontally with a slight tilt to the horizon as in steeply sloping layers.

Of great importance is the degree of destruction and the fissuration of a stratum. Cases have been observed when, in blasting enemy mine galleries situated in rocky strata which were fairly similar in composition but dissimilar in degree of fissuration, the various blocks of massive rock did not so much crumble away as dislodge and replace each other, with the result that the galleries only narrowed down and got out of alignment. In fissured sandstones, having thin clayey seams, heavy explosions were observed to cause marked twists (up to 7.5 meters) of the horizontals at the fissures along these clayey seams. The mine galleries were not destroyed despite the fact that the walls were not braced.

In calculating the size of a charge under diverse geological conditions an accounting is taken of the composition of the strata, their solidity, occurrence, degree of weathering, of fissuration, of water saturation, etc. Without this information the sapper who is not sufficiently acquainted with the geological conditions is apt to make serious blunders. The advice of a military geologist can render him great and valuable aid.

[The section entitled "Importance of Sound Conductivity of Strata" is devoted to general observations of the extent to which sound conduction depends on the type of sound most frequently occurring in underground works and the characteristics of strata through which sounds are transmitted. These observations are summarized in Table 11 which is supplemented by another table from an Italian source]

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Table 11. Distances from which Sounds are Audible in Strata*

Nature of the Sound	Strata	Distance in Meters Without Instrument	With Seismo-stethoscope
Work with pickaxe	Chalk	45	90
	Clay	38	49
	Sandy clay	15	30
Work with shovel	Chalk	21	37
	Clay	15	34
	Sandy clay	3	9
Walking on wooden floor	Chalk	15	24
	Clay	12	18
	Sandy clay	3	7.6
Falling soil	Chalk	11	18
	Clay	9	15
	Sandy clay	1.5	6.1
Dragging sacks of earth	Chalk	6	17
	Clay	4.6	10.5
	Sandy clay	1.5	5.5
Conversations	Chalk	3.65	15
	Clay	2	9
	Sandy clay	1.5	4.6

*Data taken from field manual for engineering troops, <u>Underground Mine Operations and Mine Warfare</u>. (Podzemnominnyye raboty i minnaya bor'ba), 1942.

Table 12. Maximum Distances (in Meters) from which Various Sounds can be Heard in Various Strata*

Nature of the Sound	Rock Hard	Rock Soft	Soil Hard	Soil Soft
1. Without Instruments				
Drilling	60-80	40-50	30-40	1-18
Breaking with shovels	20-25	15-20	10-20	2- 5
Walking on wooden floor	12-25	14-16	10-15	2- 5
Falling waste or landslips	10-15	8-12	8-10	1- 2
Dragging of materials	10-25	5-15	4- 3	1- 4
Conversations	5-10	3- 5	2- 4	1- 2
2. With Aid of Seismostethoscope and Geophone				
Drilling	120-160	90-100	45-55	25-35
Breaking with shovels	40-60	30-40	30-40	10-12
Walking on wooden floor	35-50	25-30	20-25	7-10
Falling waste or landslips	25-40	18-20	15-20	6-10
Dragging of materials	20-40	15-25	10-15	5-10
Conversations	20-30	15-20	5- 8	3- 5
3. With Aid of Seismomicrophone				
Drilling	80-120	60-70	40-50	20-25

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Table 12 (Contd)

Nature of the Sound	Rock Hard	Rock Soft	Soil Hard	Soil Soft
Breaking with shovels	30-40	20-30	20-25	6-10
Walking on wooden floor	25-35	20-25	15-20	5- 7
Falling waste or landslips	15-25	14-16	10-15	4- 6
Dragging of materials	15-30	10-20	6-10	3- 6
Conversations	10-20	10-25	3- 6	2- 3

*Data taken from the Italian Manual for Mining and Blasting Operations, Part II -- Mine Works, 1937.

[The section on "Gas Permeability of Strata" stresses the importance of studying the capacity of various strata for retaining and absorbing poisonous gases. The greater the fissures, the easier gases can find their way into the galleries and underground chambers. The military geologist must supply the requisite information.]

[Another section deals with the role of the color of strata in camouflaging underground works. The observations are of a general character. Strata may change their color with the progress of excavation in depth; brightly colored strata are hard to camouflage; strata change their color when they dry out, etc. By knowing the color of the strata it is possible to establish the levels at which the enemy is digging his own underground galleries.]

Military-Geological Servicing of Underground Mine Works

Military-geological servicing of underground mine works is of paramount importance. The diversity of geological problems arising in connection with underground excavations, has a definite effect on the work of the military geologist. It becomes especially complicated in underground excavations undertaken in the immediate proximity of the enemy, when offensive mine galleries must be laid under enemy-held territory.

The military geologist and mine expert are compelled at times to be satisfied with only meager observations, not always conducted at points most helpful for the clarification of the geological situation. Sometimes they are necessarily restricted to geological materials on hand in the form of military-geological maps, handbooks, etc.

However, despite the fact that the military situation in most cases hinders execution of field geological observation, it is nevertheless necessary for successful execution of underground mine operations to get accurate data.

As a rule, it is not possible to secure adequate geological data on the forward edge before the beginning of underground mine works. Therefore, geological observation must be carried on throughout the course of work. The data gathered as a result of these observations permit correction of the geological situation assumed in the operational plan of mine works. Observations conducted throughout the entire period of underground mine excavations are especially necessary in view of the fact that practical problems are constantly arising in connection with the various phases of underground mine work, such as bracing, prevention of deformations of the strata, removal of water, organization of listening posts, calculation of the size of explosive charges, reduction of the gas conductivity of the strata, etc.

Details of the geological situation can only be obtained after uncovering the strata.

In manuals on underground mine work and mine warfare appropriate

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attention is given to military geological reconnaissance.

The manual on underground mine works for engineers states "The composition and character of the occurrence of soils, the height of the water table for every underground construction must be determined by geological-engineering reconnaissance.

"The aim of geological-engineering reconnaissance is to establish the conditions for the construction of underground installations and the waging of mine warfare in a place selected by tactical decision. It is carried out by:

"(1) Study of geological maps, handbooks, and local materials; (2) reconnaissance with prescribed itinerary in which geological information is gathered through observation of the relief, the run-off of surface waters, [water] sources and outcroppings; (3) drilling with the aim of mapping the geological profile of the area along the axis of the proposed construction."

These rules of the manual require further supplementation, as follows:

1. It is not practically possible in every case to undertake time-consuming prospecting, requiring specialized equipment.

2. Most often the geological situation must be appraised on the basis of previously gathered material, in the form of maps, handbooks, etc. Specialized military-geological maps play as important a role in underground mine works as topographical maps play in the planning of operations for tank warfare.

3. Decisions on the tactical conduct of mine warfare should precede the study of maps, cross sections and other available material dealing with geology.

As a rule, geological maps, cross sections and various other tabulated information are available for almost every territory in which underground operations can be conducted. In most cases, however, the data is scattered and requires preliminary processing.

Often one is forced to use small-scale geological maps when more detailed geological maps are not available.

Large scale geological maps (scale 1:10,000 and 1:25,000), as is known, are to be found for numerous areas of Western Europe. For Eastern Europe maps of this type are restricted to densely populated and highly industrialized areas. Specialized large-scale maps for underground mine works are drawn beforehand for regions determined by the command or after the commencement of military operations.

Maps must always be accompanied by profiles (cross sections) in various directions and primarily in the direction of the intended course of the galleries.

Often recourse is had to the construction of more descriptive block diagrams and axonometric cross sections. Likewise, specialized, military-geological cross-section columns are of value in underground mine works (Figure 39).

However, maps and cross sections alone often prove insufficient for the solution of practical problems which arise in underground mine warfare, and supplementary military-geological investigation in the form of surveying and reconnaissance are required. In manuals of underground mine works prescribed itinerary and drilling reconnaissance are mentioned.

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A reconnaissance party is headed by the commander of a combat-engineer battalion, or by the experienced commander of a combat-engineer company, less often by the commander of a combat-engineer platoon. If the geology of the area is simple, if the conditions are favorable to observation, and if the commander in charge of the reconnaissance group has sufficient experience in geological observation, the information gathered may prove to be adequate for the solution of all practical problems. However, if the geology of the area is complicated, if combat conditions hinder carrying out the necessary observations, if the commander of the engineering unit does not have adequate geological training or the necessary experience which would allow him to make the requisite generalizations from a limited number of facts, then such reconnaissance will not only fail to be useful but may prove harmful. In such a case recourse is had to the aid of military geologists, who know the peculiarities of field underground operations.

The military geologist's aid to the command varies greatly in character. In some cases this aid may be limited only to supplying geological information which is used as the basis of operational and tactical plans of mine works. In other cases the military geologist undertakes military-geological reconnaissance and the necessary observations while underground work is going on. These geological and hydrogeological observations connected with underground excavations have great practical value.

The military geologist can render great aid to the command by determining the position of the enemy. Information concerning what levels the enemy is working or is able to work in and what difficulties he may encounter must be communicated by the military geologist to the commander immediately. Aerial-photographic materials, captured documents, and the interrogation of prisoners should assist him in securing the necessary information.

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